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PERFORMANCE CHARACTERISTICS OF A DIESEL NOZZLE TESTER USED AS A HAND HOMOGENIZER

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SUMMARY

The performance characteristics of a diesel nozzle tester used as a hand homogenizer have been investigated. It has been found that the instrument is capable of homogenizing milk samples as small as several ounces according to the definitions of homogenization. Homogenization efficiency as a function of homogenization pressure and recycling has been studied. The employment of suitable spray-arresting baffles, it has been found, increases homogenization efficiency markedly and prevents the incorporation of air as fine foam. The reconstituted milk obtained by injecting butter oil into skimmilk has been found to resemble market milk in appearance and in its creaming properties.

Inquiry concerning the availability of homogenizers capable of homogenizing several ounces of milk according to the definitions of homogenization led to the study of the performance characteristics of a diesel nozzle tester used unconventionally—this after accumulated evidence made it clear that commercially available small-scale emulsifiers would not serve the purpose.

Sata and his collaborators (4) described the use of a diesel nozzle tester equipped with holder and nozzle for emulsification purposes, but their data do not permit conclusions to be safely drawn concerning the adaptability of the tester combination for the more rigorous requirements of homogenization. Experiments reported in this paper show that in practice and even more so in principle, the diesel nozzle tester combination is capable of homogenizing small samples of milk to satisfy one or more proposed definitions of homogenization (5).

In the homogenization of milk the effects of pressure, nozzle type, spray-arresting baffles, and recycling were studied. In the reconstitution of whole milk from butter oil and skimmilk, the effects of pressure and temperature were studied. The apparatus lends itself to the study of the reconstitution of butter-like products from butter oil and skimmilk. Results pertaining to this aspect of our investigation will not be reported in this paper.

EXPERIMENTAL PART

The diesel nozzle tester. Nozzle test equipment is supplied by a number of manufacturers of engine equipment. Although an American Bosch tester [1] was used, different makes operate on the same principles and it is to be anticipated that no far-reaching difference in results would be obtained on the substitution of one tester for another. As the name implies, the tester is used conventionally

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[1] The mention of trade names in this paper is for identification and implies no endorsement of the products.

to test the performance characteristics of diesel engine nozzles and holder assemblies with respect to the following: leakage at the nozzle seat; spray pattern and chatter; and nozzle opening pressure. The test stand, comprising a fuel injection pump and accessories, connects through small-bore high-pressure tubing with a nozzle holder which holds the nozzle in the correct position and provides a means of conducting oil to the nozzle at a regulated pressure. There are two types of nozzles, the hole and the pintle type. One type of hole nozzle has a 120° conical nose, and the spray issues at an angle of 120° through a

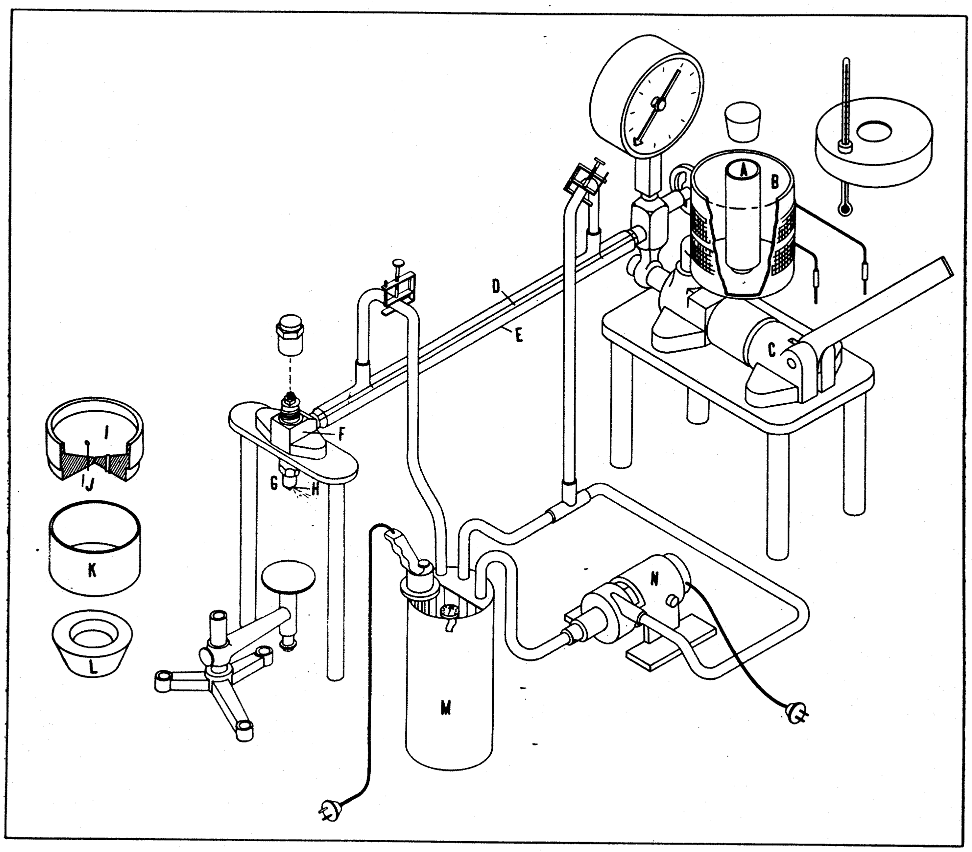

FIG. 1. Hand-homogenizer assembly featuring the Diesel nozzle tester.

0.3-mm. diameter hole in the wall of the cone. A second type of hole nozzle has a flat nose, and the spray issues in the direction of the axis through a hole, 0.2 mm. in diameter. The pintle type nozzle is characterized by a pin or pintle projecting a short distance through an opening at the flat end of the nozzle to form an annulus (see Figure 1A). The lower end of a spindle bears on the stem of the nozzle, the upper end on the spring. The upper end of the nozzle and the lower end of the holder are provided with mated, accurately ground and lapped surfaces. The nozzle is secured to the holder by means of a cap nut.

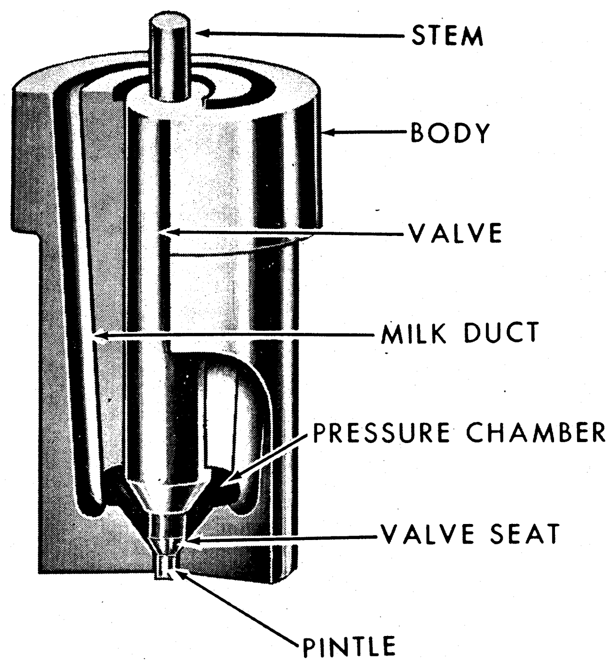

FIG. 1A. Sections of a pintle nozzle.

The injection pump has a displacement of about 0.3 cc. The pressure (capable of regulation) is read on a valve-controlled pressure gauge reading to 5,000 lb. per square inch.

The homogenizer assembly. The homogenizer assembly featuring the nozzle tester is shown in Figure 1. The following modifications of a typical nozzle holder tester combination may be noted: Sample holder (A) has replaced an oil-filter; what was once an oil reservoir has become now a constant temperature bath (B); the high-pressure connecting tube (D) has been surrounded by a jacket (E). A receiver assembly which will be described in the following section has been added.

The homogenization of milk. Because the pressure gauge shown in Figure 1 is nonsanitary in construction, it must be by-passed as a matter of convenience during the processing of milk.

This is accomplished by setting the pressure before the milk is pumped through the apparatus. The opening pressure of the nozzle valve (G) is determined by the number of screw threads showing on the pressure-adjusting screw located at the upper end of the nozzle holder (F). The pressure as a function of the number of exposed screw threads is determined by passing a test oil (three parts transformer oil and one part white kerosene) with the gauge open and operating.

Once the adjusting screw has been calibrated, the gauge is by-passed by closing the gauge valve, and thereafter pressure readings are made by referring to the calibration curve. This curve relating the number of screw threads with the pressure gauge reading is linear, and is valid over long periods of time.

Clarified milk at room temperature is introduced into holder (A). On the forward stroke of the plunger in pump (C) the milk is forced through small-bore high-pressure connecting tubing (D), and is brought during the course of its passage therein to the temperature of homogenization by heat exchange with propylene glycol circulating through jacket (E) and issuing from constant temperature bath (M). The heated milk passes through nozzle holder (F) into nozzle body (G), and when the pressure of the milk exceeds the pressure on the nozzle valve the milk issues through the 0.3-mm. opening (H). The spray is not allowed to develop, but is arrested at the walls of the stainless steel funnel (I) which surrounds the nozzle cone and presses firmly against it. Homogenized milk accumulates in the funnel and overflows through openings (J) into reservoir (K) resting on the play-allowing rubber stopper (L) which in turn rests on a platform capable of being raised and lowered.

Milk is clarified prior to processing by vacuum filtration through eight sediment testing discs arranged in a Seitz funnel. Large foreign particles which may enter the sample accidentally after clarification are removed by a small, fine-mesh wire filter screen lodged in the connecting adapter of the nozzle holder.

Reconstitution of whole milk. In the reconstitution of whole milk from skimmilk and butter oil, melted butter oil introduced into holder (A) is brought approximately to the processing temperature by heat exchange with hot water in water-bath (B), and exactly to the temperature as it passes through the jacketed connector tube (D). The butter oil issues from the opening in the nozzle directly into the external phase, skimmilk, which just covers the opening.

Methods of analysis. Homogenization efficiency was determined by the spectrophotometric method of Deackoff and Rees (2), supplemented on occasions with measurements of the rate of creaming. The homogenization indices were corrected to apply to milk containing 3.5% fat. Fat determinations were made by the Roese-Gottlieb method (1).

RESULTS

Effect of nozzle type. Table 1 shows the results of an experiment in which the nozzle type was varied. Two modes of operation were employed. In one the spray was allowed to develop partly before being trapped, and in the other the spray was arrested prior to development, by means of suitable baffles [the close fitting funnel (I) with the hole-type nozzle, and a flat glass plate with the pintle-type nozzles]. The hole nozzle gave the best results with both the open and arrested spray techniques. The employment of baffles increased homogenization efficiency markedly. The pressure capability of the instrument could not be fully realized with milk. Seepage between the lapped guide surfaces of the nozzle valve and body, although necessary in small amounts for lubrication, became serious as the pressure was raised above 2,300 lb. per square inch with the pintle-type nozzle installed in the assembly, and above 3,000 lb. per square inch with the hole-type nozzles. The full pressure capability of the nozzle valve according to Sata (4) exceeds 15,000 lb. per square inch.

TABLE 1
Influence of spray nozzle type and baffling on homogenization efficiency

Nozzle type	Pressure	Homogenization index
	(lb/sq in.)	*(%)*
Hole (0.3 mm. in conical nose)	2,250	59.7
Hole (0.3 mm. in conical nose)	3,000	65.0
Hole (0.3 mm. in conical nose)[a]	2,250	62.3
Hole (0.3 mm. in conical nose)[a]	3,000	68.0
Hole (0.2 mm. in flat nose)	2,250	47.3
Hole (0.2 mm. in flat nost)	3,000	49.0
Hole (0.2 mm. in flat nose)[a]	2,250	50.8
Hole (0.2 mm. in flat nose)[a]	3,000	55.5
Standard pintle	2,250	48.7
Standard pintle	3,000	52.2

[a] Close-fitting baffle was employed.

Effects of homogenization pressure. Preliminary experiments showed that no gain in homogenization efficiency accrued to the use of homogenization temperatures exceeding 160° F. This is in agreement with the homogenization studies of Deackoff and Rees (2). The preliminary experiments also showed that heated milk could not be pumped through the system without binding of the pump plunger in its barrel. As a remedial measure the milk samples were introduced into the pump at room temperature, acquiring thereafter the proper homogenization temperature on passage through the jacketed small-bore connecting tube. The hole nozzle was employed, and results were obtained both with open and arrested sprays.

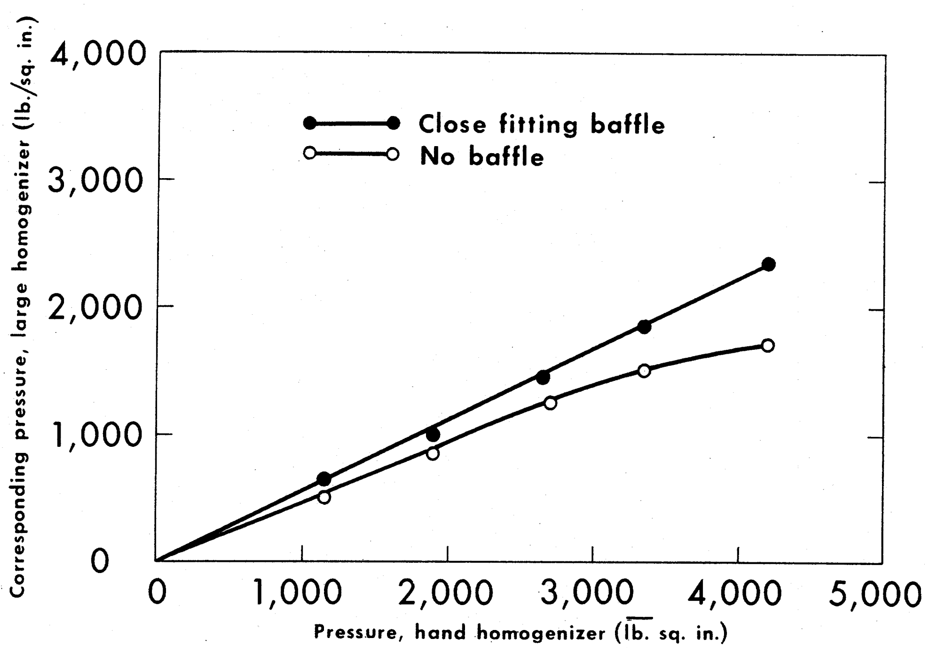

FIG. 2. Relationship between the pressures required with the hand-homogenizer and a plant-scale homogenizer to yield the same homogenization efficiency.

The results plotted in Figure 2 show as abscissae the homogenization pressure, and as ordinates the corresponding pressure required with a conventional 125 gal.-per-hour plant homogenizer to achieve the same degree of homogenization. The employment of a close-fitting baffle improves efficiency markedly, especially in the high pressure range. The corresponding pressure is proportional to the pressure employed in hand homogenization and the constants of proportionality are 0.55 and 0.45, respectively, depending upon whether a baffle has been employed. The direct proportionality holds only over a limited pressure range if a baffle is not employed, and under such conditions at high pressures very little gain is obtained as homogenization pressure is increased.

The effect of recycling. Recycling at a fixed and relatively low homogenization pressure may be used in lieu of high homogenization pressures to effect a high degree of homogenization (2, 3). In Figure 3 the relationship is shown

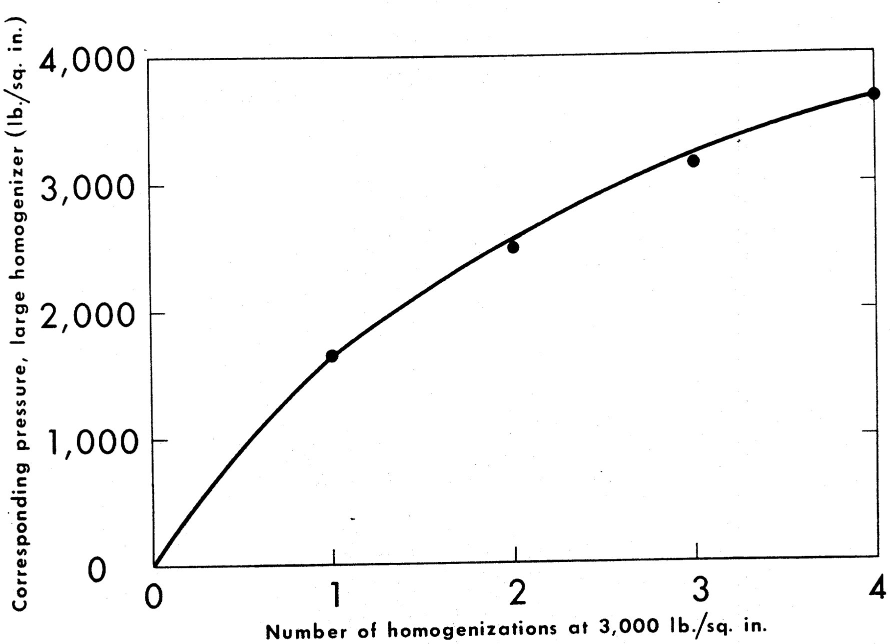

FIG. 3. Relationship between the number of homogenizations at 3,000 lb. per square inch in hand-homogenization and the corresponding pressure in large-scale homogenization required to achieve the same homogenization efficiency.

between the number of homogenizations at 3,000 lb. per square inch and the corresponding single-pass homogenization pressure required to achieve the same degree of homogenization with a plant-size homogenizer. One and four passes through the hand homogenizer at 3,000 lb. per square inch give the same results as one pass through a plant homogenizer operating, respectively, at approximately 1,700 and 3,700 per square inch. The data plotted in the graph were obtained with the funnel baffle in place, and under conditions in which the unprocessed milk in the dead space of the apparatus was removed after each pass.

Rehomogenization of homogenized milk. Milk samples were homogenized at pressures up to 4,000 lb. per square inch in a 125 gal.-per-hour plant-scale homogenizer. These samples were then passed through the hand-homogenizer at 4,450 lb. per square inch. The open-spray technique was employed. Turbidity measurements were made on all samples. The data contained in Table 2 show quite clearly that rehomogenization of well-homogenized milk by means of the hand-homogenizer results in further improvement of the degree of homogenization. Thus, the homogenization index of milk homogenized at 4,000 lb. per square inch was increased from 81.8 to 84.5 upon rehomogenization of the

TABLE 2

Increase in homogenization index attending rehomogenization of milk samples which had undergone homogenization at various pressures in plant scale homogenizer

Homogenization [a] pressure	Rehomogenization [b] pressure	Homogenization index
(lb/sq in.)		(%)
None	None	40.5
500	None	42.9
1,000	None	50.2
2,000	None	70.0
2,500	None	73.3
4,000	None	81.8
5,000	None	84.0
None	4,450	69.0
2,000	4,450	75.8
2,500	4,450	78.1
4,000	4,450	84.5

[a] Commercial homogenizer employed.
[b] Hand-homogenizer employed.

sample at 4,450 lb. per square inch in the hand homogenizer. An homogenization pressure exceeding 5,000 lb. per square inch would have been required to effect the same high degree of homogenization in a single-pass operation in a commercial homogenizer.

Reproducibility. A point of interest if the hand-homogenizer is to be employed in investigational work is the degree to which the results may be reproduced. Accordingly, five samples of the same market milk were passed through the hand-homogenizer at 3,000 lb. per square inch, with the baffle in place. Homogenization indices ranging from 68.1 to 68.7 were obtained corresponding, respectively, to the pressure range 1,650 to 1,750 lb. per square inch in conventional homogenization.

Reconstituted milk. Certain aspects of research work require the reconstitution of whole milk from skimmilk and butter oil. The nozzle tester is particularly well suited to accomplish this end. The butter oil is injected directly into skimmilk contained in a suitable holder. In the first series of experiments, 40 g. of skimmilk pasteurized at 64° for 30 min. and held approximately at that temperature during homogenization served as the external phase. The injection pressure at a temperature of 71° C. was varied from 2,250 to 4,450 lb. per square inch. The nozzle opening was located 0.5 cm. below the skimmilk surface. A preliminary run showed that approximately 0.25 g. butter oil was delivered per stroke. Six strokes per 40 ml. milk delivered sufficient fat to yield a milk containing slightly more than 3.0% fat. Final adjustment to 3.0% fat was made by adding skimmilk. The fat content was determined by weighing the skim and reconstituted milks. Table 3 shows the results of the experiment. The cream line developing after 17 hr. of storage of the milk at approximately 5° C. is taken as a measure of the effectiveness of reconstitution. Homogenization indices also are given, but these have very little meaning for transmittances corresponding to very low degrees of homogenization. At high injection pressures a reconstituted milk is obtained, the creaming property of which resembles that of market milk. The full pressure range of the instrument was not used, inasmuch as the data over the limited range showed that the gain in dispersibility as measured by the decrease in the height of the cream layer would be small.

TABLE 3

Rate of creaming in reconstituted milks

Injection pressure	Skimmilk temperature	Cream line [b] after 17 hr. (relative)	Cream line after 96 hr. (relative)	Homogenization index
(lb/sq in.)	*(° C.)*			*(%)*
2,250	64	2.4	....	35.5
3,000	64	1.9	....	37.3
3,720	64	1.4	....	38.6
4,450	64	1.2	1.2	40.0
4,450	15	1.1	2.2	41.0
4,450	76	Patch	1.0	39.2
Whole milk control [a]		1.0	1.0	40.0

[a] Whole milk pasteurized at 64° for 15 min.
[b] Height of cream line relative to control taken as 1.0 developing at approximately 5° C.

In a second series of experiments, the temperature of the skimmilk was varied from 15 to 76° C. and butter oil at 71° C. was injected at a pressure of 4,450 lb. per square inch. The cream layer in the low-temperature reconstituted milk, although comparable in volume after 17 hr. of storage at 5° C. to that on the control milk, continued to develop on prolonged storage. More closely resembling the behavior of the control milk in creaming was the reconstituted milk which had been prepared from skimmilk held at a temperature of 64° C. during injection of the butter oil. The cream layer on the high-temperature (76°) reconstituted milk developed quite slowly to the same volume as that on the control.

DISCUSSION

Homogenization probably takes place at the valve seat (see Figure 1A) rather than at the orifice. Thus, the degree of homogenization obtained with the hole-type nozzle, the orifice of which was 0.3 mm. in diameter, was greater than that obtained with the hole-type nozzle, the orifice of which was smaller, that is, 0.2 mm. in diameter. Additional effective stress was acquired by the employment of a close-fitting baffle. This was particularly marked with the use of the funnel adapted to the conical nose of the hole-type nozzle. The baffle was indispensable in situations in which recycling was required. Collection of a spray only partially arrested resulted in the incorporation of finely dispersed air which required removal prior to the recycling of the sample. With the employment of the funnel, the nozzle opening was submerged in milk and the spray was trapped in the small quantity of milk lodged between the funnel wall and the wall of the conical nose.

Better performance was obtained with the hole-type than with the pintle-type nozzle. The projecting pintle made it difficult to operate with a close-fitting baffle, and the higher pressures available with the employment of the hole-type nozzles could not be reached with the pintle-type.

It would appear from the results of Deackoff and Rees (2) that commercial homogenized milk will have a light transmission index of about 70% corresponding to a U.S.P.H.S. index of 6. The same reference sshows that a light transmission index of 65% corresponds to the maximum allowable U.S.P.H.S. index of 10. The results in Table 1 and 2 show that the U.S.P.H.S. definition is satisfied if homogenization with the hand-homogenizer is carried out at pressures exceeding 3,000 lb. per square inch in a single cycle operation, and at pressures of approximately 3,000 lb. per square inch in a multicycle operation containing two or more cycles.

The results on reconstitution of whole milk are interesting in the sense that the product which was obtained resembled quite closely market milk with respect to the rate of creaming. Dispersion of the butter oil was quite effective even without the addition of emulsifiers and no oiling-off was observed. Simplified and stripped of certain nonessentials for the purposes of handiness, the nozzle tester may very well serve as a household appliance for the reconstitution of milk from skimmilk and butter oil.

The nozzle tester is a precision instrument and as such it demands adequate care. In addition to the care which must be observed in routine use of the instrument, there are the precautions which must be observed when the tester is used as a hand homogenizer. Although the materials of construction are such that all lapped surfaces and close-fitting parts hold up well during repeated use, there are parts which rust very easily when exposed to aqueous solutions and moisture. Consequently, the equipment must be disassembled after every run, and exposed parts must be thoroughly rinsed, washed with mild detergent, rinsed again, flushed with alcohol, and dried in a current of filtered air. The parts prone to rust are best stored in transformer oil until ready for use. The tester falls apart easily, and is easily reassembled. Approximately 15 min. are required for disassembling and cleaning, and the same time should be allowed for reassembling. In spite of all precautions which may be taken, it is difficult to avoid the incorporation during homogenization of small amounts of a very fine sediment which, however, is easily removed by means of a centrifuge.

There is no reason to doubt that all exposed parts could be made of stainless steel without altering the design of the tester, and that a stainless steel sanitary gauge reading to 10,000 lb. per square inch could be substituted for the gauge now provided. Such alterations would improve performance considerably and broaden the use of the instrument. There is approximately 22 ml. of dead space which must be loaded with sample prior to pumping. This milk is not recovered. The advantages which would accrue to the elimination of the dead space as much as possible would be particularly noticeable in those instances in which recycling forms part of the operation.

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